Image enhancement of high digital magnification for patients with central vision loss

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ABSTRACT

We have developed a mobile vision assistive device based on a head mounted display (HMD) with a video camera, which provides image magnification and contrast enhancement for patients with central field loss (CFL). Because the exposure level of the video camera is usually adjusted according to the overall luminance of the scene, the contrast of sub-images (to be magnified) may be low. We found that at high magnification levels, conventional histogram enhancement methods frequently result in over- or under-enhancement due to irregular histogram distribution of sub-images. Furthermore, the histogram range of the sub-images may change dramatically when the camera moves, which may cause flickering. A piece-wise histogram stretching method based on a center emphasized histogram is proposed and evaluated by observers. The center emphasized histogram minimizes the histogram fluctuation due to image changes near the image boundary when the camera moves slightly, which therefore reduces flickering after enhancement. A piece-wise histogram stretching function is implemented by including a gain turnaround point to deal with very low contrast images and reduce the possibility of over enhancement. Six normally sighted subjects and a CFL patient were tested for their preference of images enhanced by the conventional and proposed methods as well as the original images. All subjects preferred the proposed enhancement method over the conventional method.

Keywords: Low vision, Vision rehabilitation, Magnification device, Contrast enhancement

1. INTRODUCTION

There are more than 2.4 million people with impaired vision in the US alone, and the number is increasing with the aging of the population. Central field loss (CFL) is commonly caused by diseases such as age-related macular degeneration, optic nerve diseases, and diabetic retinopathy[1]. Central visual impairment is characterized by a loss of high resolution vision causing decline of both contrast sensitivity and visual acuity. These problems result in difficulty recognizing faces, reading, watching TV, and performing everyday tasks[2].

Central visual impairment can be improved by magnification and contrast enhancement. Optical devices are widely used in rehabilitation because they are relatively inexpensive and portable. However, they have limited magnification and lack contrast enhancement. Electronic magnification systems including stationary and portable closed circuit televisions (CCTV) and head mounted display (HMD) systems were designed to overcome the limitations of optical devices and provide high magnification with some enhanced of contrast[3]. Several HMD devices have been developed over the years, including the Low Vision Enhancement System (LVES)[4], Jordy, Flipperport and NuVision. These HMD devices have been shown to be helpful to patients with low vision improving visual acuity (VA)[5, 6].

Magnification and contrast enhancement in HMD devices are usually both adopted to improve the patients' vision. Although these devices are effective to improve visual acuity by magnification, one study found that all commercially available HMD devices (Jordy, Flipperport and NuVision) actually reduce contrast sensitivity (CS)[5]. We believed that it is because the contrast enhancement algorithms in those devices could not properly deal with low contrast images. This problem may present especially at high magnification levels. Usually, the video camera capturing scene images adjusts exposure levels according to the overall luminance of the scene, resulting in an image that is optimal for the full range of luminance representation. The overall exposure level may not be appropriate for the sub-image to be magnified, and therefore may result in sub-images that are too dark, too bright, or low contrast. When access to the camera's exposure control is not available, enhancement on the sub-images may be necessary. Contrast stretching is a commonly used image enhancement technique that attempts to improve the contrast by mapping the range of intensity values it contains to a desired range of values. A commonly used approach is modification of histogram, such as histogram equalization and histogram stretching. Histogram equalization was used by Leat[7] for low vision enhancement over the whole image

and was not successful. We found that the conventional histogram stretching algorithm often does not work well either for images at high magnification levels. One problem is that a small number of brighter or darker pixels of incidental features at the boundaries of the sub-image can substantially extend the histogram range, which would result in under-enhancement. These edge features entering or departing the sub-image due to small camera movements may also cause dramatic change in the histogram distribution, and therefore result in flickering[8]. Another problem is that the intensity range of the sub-image at high magnification levels is often narrow. The conventional histogram stretching method always attempts to map the narrow intensity range into the full permissible range, and that may lead to over-enhancement when the sub-image has a very narrow range of luminance. To address these problems, we proposed and implemented a piece-wise contrast stretching algorithm based on a center-emphasized histogram.

2. METHODS

2.1 Contrast enhancement algorithms

The proposed contrast enhancement algorithm differs from conventional contrast stretching methods on two aspects: histogram counting and stretching function.

Center emphasized exposure control has been implemented in some cameras. This method places equal (and more) weight on the image central area, and the weight change across the image is not continuous. In our proposed method, a Gaussian weight function is applied spatially when counting the histogram. The intensity histogram weighted by this Gaussian function will reduce the impact of dark or bright features near the image segment edge. It will help to avoid the under-enhancement problem due to edge features, and the smoothly changing weight will help to mitigate histogram fluctuation caused by entering or departing incidental features across consecutive video frames.

For the histogram stretching function, a turnaround point is introduced to deal with the narrow histogram range, as shown in Figure 1. Above the turnaround point, gain is inversely proportional to the histogram range, as in conventional histogram stretching[9]. When the histogram range decreases below the turnaround point, gain is proportional to the histogram range, declining eventually to no enhancement when the sub-image has only a few gray levels. In the latter case, the stretched histogram does not cover the full permissible range (0 to 255), it may be located at the low end (dark) or high end (bright). Therefore, the intensity range is shifted to have a mean of 128 making the image more visible.
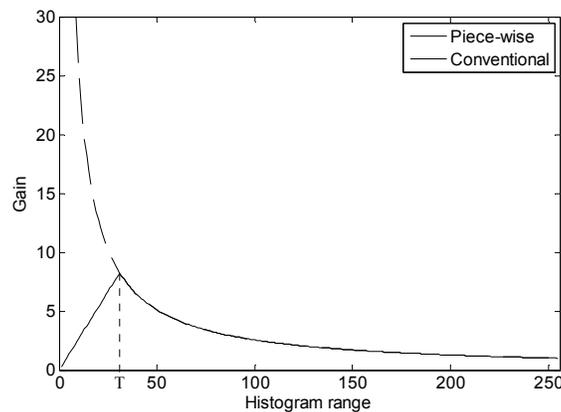
Figure 1. Piece-wise histogram stretching function. The gain of piece-wise stretching function is inversely proportional to the histogram range above the turnaround point (T), and is proportional to the histogram range below the turnaround point, declining eventually to minimal enhancement when the sub-image has only a few gray levels. The gain of conventional stretching function is always inversely proportional to the histogram range, even beyond the turnaround point as the dashed curve indicates.

In this study the histogram stretching is applied to the image intensity (luminance). Color images are first converted into YCbCr, and only the luminance component Y is processed. Then the enhanced luminance component and chrominance components (CbCr) are converted back to RGB color space. In this study, the images were processed off line by conventional and proposed contrast stretching algorithms with fixed parameters: the σ of Gaussian weight function is 40% of sub-image width, and the turnaround point of stretching function T was set to 30.

2.2 Evaluation of Histogram Counting Methods

Four 1600x1200-pixel images (indoor furniture, people outdoors, an aquarium tank, and butterfly samples) were selected from our image database to evaluate the conventional and proposed contrast stretching methods (Figure 2).
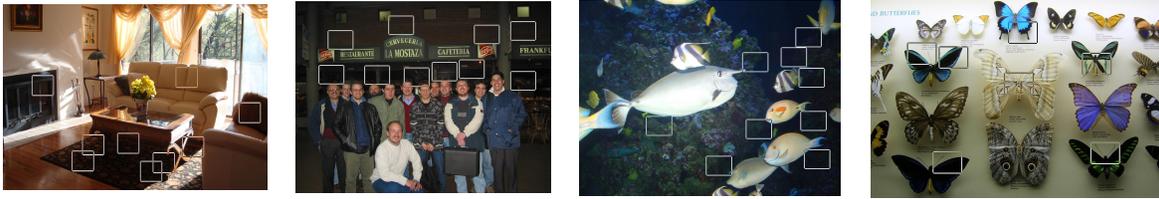
Figure 2. Whole images used in the two evaluations. The regions of interest were marked by brighter rectangles.

These images represent the common situation in which the luminance exposure is appropriate for the image as a whole, but not for every small regions. Testing was performed under a 10x magnification level thus sub-image size was 160x120 pixels.

We first compared the Gaussian weighted histogram versus the conventional equally weighted histogram in a histogram counting method evaluation. Thirty four region/objects of interest were selected manually. These points of interest were selected to have dark or bright incidental features near them. Twenty eight sub-images surrounding the point of interest were extracted, and shown to subjects sequentially from top to bottom and from left to right in a video fashion at 25 frames per second, to simulate the magnified view through a HMD with slight movement of the head/camera. In each trial, three versions of a sub-image video, original, enhanced with conventional method, and with the proposed method, were presented side by side on a LCD monitor (Dell, 2007FPb). Each sub-image subtended 7.8° (H) by 5.5° (V) at a 0.5-meter distance. Subjects selected their most preferred version in each trial, but with additional options of selecting two or no preference difference for all three versions if multiple versions appeared to be visually the same or they were preferred equally. Thus, the selection percentage reflects the proportion of one version preferred over at least another version. The subjects were instructed to make their selection accounting for the details, artifacts, and image flickering present in the videos, and they balanced these factors on their own.

2.3 Evaluation of Histogram Stretching Functions

After a potential advantage of the Gaussian weighted histogram was found, we then compared the preference for the piece-wise stretching function versus the conventional linear stretching function based on the Gaussian weighted histogram. Each of the 4 images was divided into 100 non overlapping sub-images. Only still images were used. The same side-by-side three images presentation method was used. Subjects selected their preferred sub-image balancing the visibility of details and level of artifacts present in the image. Same as in the histogram evaluation (2.2), subjects were allowed to select more than one version of images if the images appeared to be visually the same or they were preferred equally.

3. RESULTS

3.1 Histogram counting methods

Here the conventional equally weighted histogram and Gaussian weighted histogram were compared. Examples of the tested sub-images are shown in Figure 3. The conventional linear stretching function was used on these histograms. With overall exposure control, the regions of interest in the original sub-images do not appear to have easily visible details. The histogram range estimated by the equally-weighted histogram counting is fairly wide because of the presence of a small bright section within a bright sub image or a dark section within a bright sub image, resulting in under-enhancement of the point of interest. With the Gaussian weighted histogram counting, the regions of interest are enhanced showing more details.

The preference rate of six normally sighted subjects is shown in Figure 4. According to Wilcoxon signed ranks test, subjects' preference for the Gaussian weighted histogram over the equally-weighted histogram approached significance (62% vs 46%, p=0.075). Subjects reported preferring the Gaussian enhanced images due to reduced flicker. Subjects significantly preferred the Gaussian enhancement over the original sub-image (62% vs 14%, p=0.028). Subjects also significantly preferred the conventionally enhanced images over the original images (46% vs 14%, p=0.028).
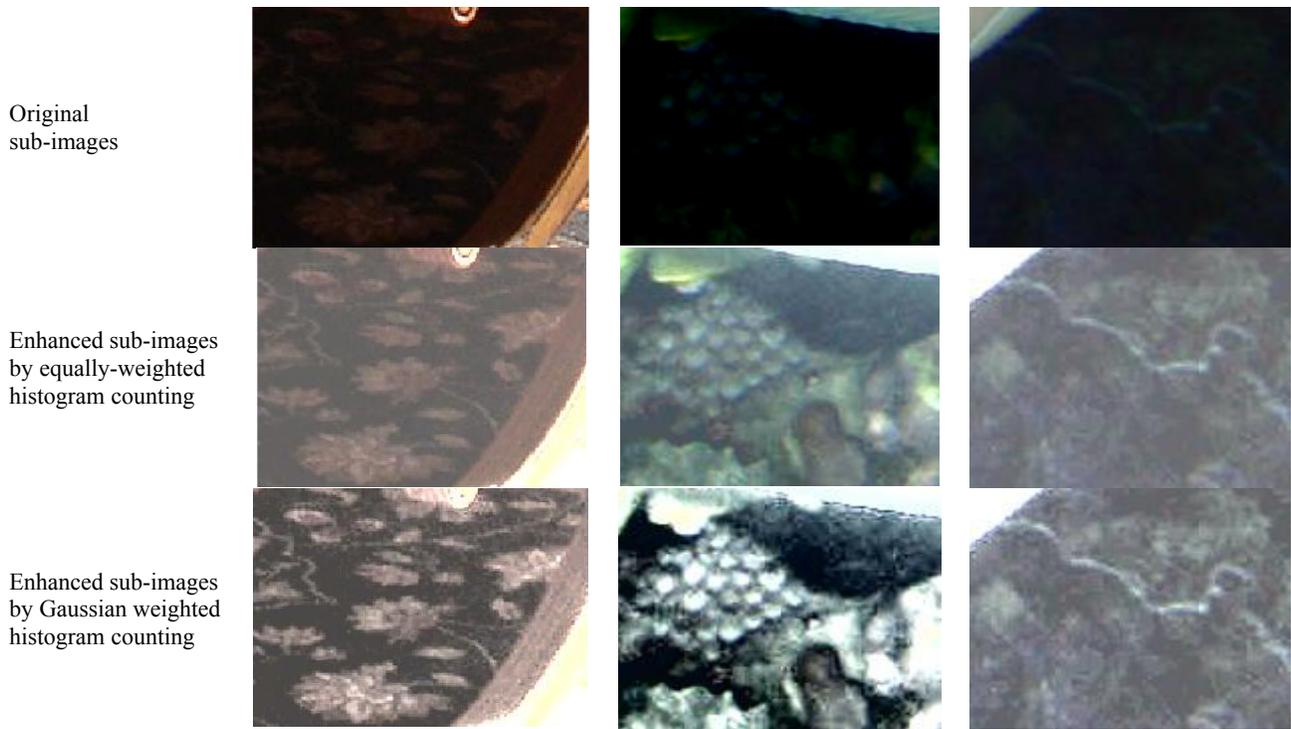
Figure 3. Examples of tested sub-images in the evaluation of histogram counting. The regions of interest in the original sub-images do not appear to have easily visible details. Enhanced sub-images by equally-weighted histogram counting and Gaussian weighted histogram counting show more details in the area of interest, but the enhanced sub-images by the latter have more details and higher contrast than that by the former.
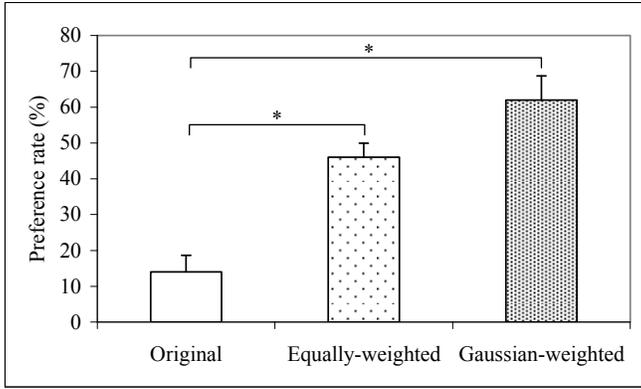
Figure 4. Preference rate of six normally sighted subjects in evaluation of histogram counting methods. They preferred the Gaussian enhanced images over the conventionally enhanced images, and significantly preferred the both the Gaussian and conventionally enhanced images over the original images.

The patient with CFL (VA=20/200, CS=0.65) never selected the original image (Figure 5). Her preference for the Gaussian histogram over the equally weighted histogram was similar to that of the normally sighted subjects (77% vs 57%), but the difference in proportions[10] of image preferred for the two methods was statistically significant (p=0.035).
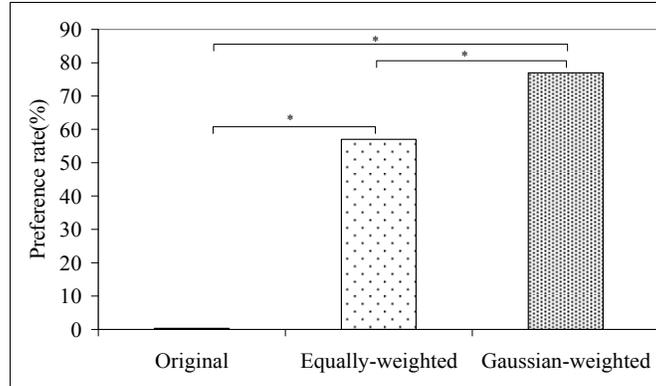
Figure 5. CFL patient's preference rate of histogram counting evaluation. She strongly preferred enhanced images over the original. Her preference for the Gaussian enhancement over the conventional enhancement is also obvious.

3.2 Stretching functions

Conventional linear histogram stretching and proposed piece-wise stretching methods was compared as well as the original images. The Gaussian weighted histogram was used in processing both enhancements. Examples of the tested sub-images are shown in Figure 6. When the histogram range was very narrow in some of the sub-images, the gain of the conventional histogram stretching algorithm is very large, which resulted in nearly binary images. These over-enhanced images were usually rejected by subjects because of the strong artifacts. However, the gain of the proposed algorithm is smaller because the histogram range is below the turnaround point. The enhanced images were mapped into a more appropriate intensity range and therefore the image was seen clearly and preferred.
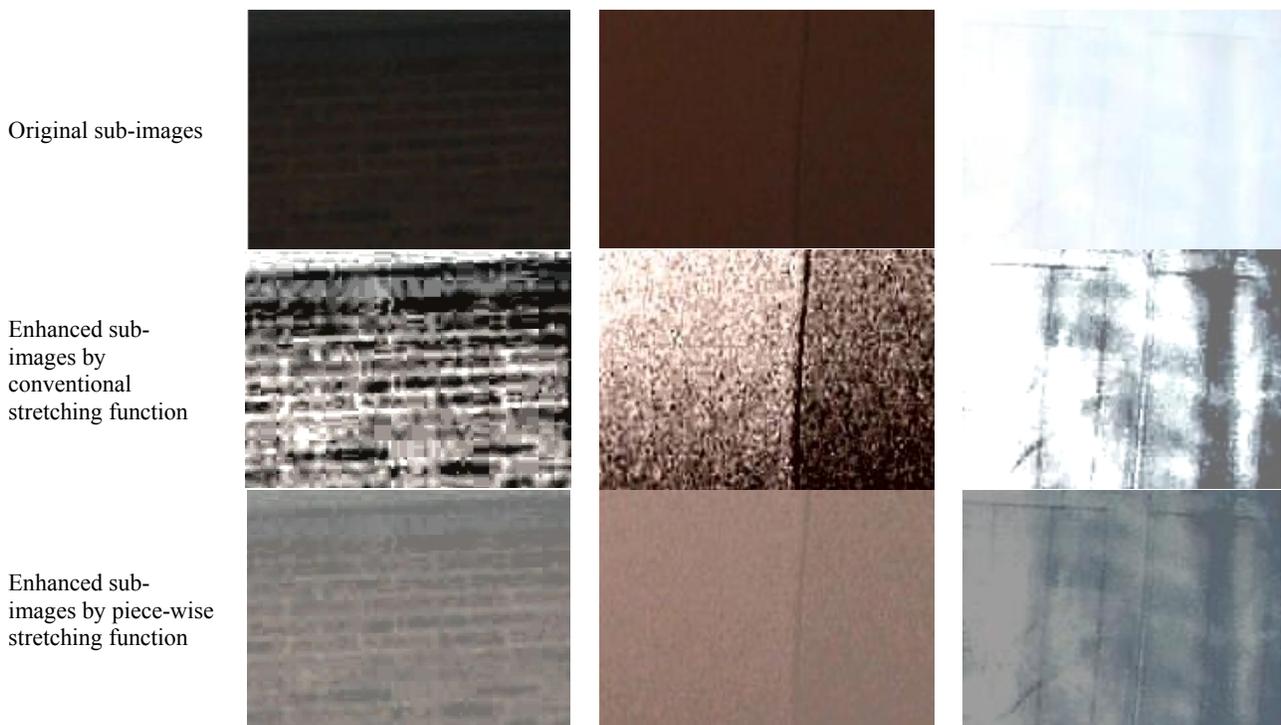
Figure 6. Examples of tested sub-images in the stretching function evaluation. The histogram range of the particular areas of interest in the original sub-images was very narrow. The enhanced sub-images by conventional stretching function are usually over-enhancement, whereas the enhanced sub-images by piece-wise stretching function can be seen clearly.

Preference rates for the six normally sighted subjects are shown in Figure 7. Subjects significantly preferred the images enhanced with the piece-wise stretching function over those enhanced with the conventional linear stretching function (43% vs 35%, p=0.028). While images enhanced with the proposed method are selected as preferred ones more often

than the original, that difference was not significant (43% vs 33%, p=0.345). There was no significant difference in preference for the conventional stretching method over the original images (35% vs 33%, p=0.6). One of the reasons why enhanced images (by either conventional or proposed method) was not significantly preferred over original images is that there was an obvious individual difference in preference rate among the 6 normally sighted subjects. Table 1 shows the preference rate of each subject. It can be seen that subject 2 and 5 showed different preferences from the others. In briefing after the experiment they reported having a low tolerance to enhancement artifacts. Another important reason is postulated in discussion section.
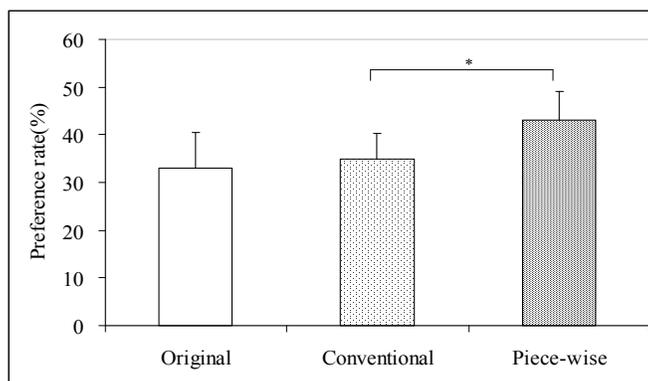
Figure 7. Preference rate of six normally sighted subjects in the stretching function evaluation. Subjects significantly preferred images enhanced with the piece-wise stretching function over the conventional stretching function.

Table 1 Preference rates of six normally sighted subjects

Subject #	Original	Conventional	Piece-wise
1	14%	43%	56%
2	50%	28%	32%
3	21%	45%	51%
4	22%	49%	61%
5	61%	15%	23%
6	30%	30%	38%

The preference rates for the CFL patient are shown in Figure 8. She significantly preferred enhanced images over original images (p<0.001), unlike the normally sighted subjects. She also preferred the piece-wise stretching function over the conventional linear stretching method (61% vs 50%, p=0.001)
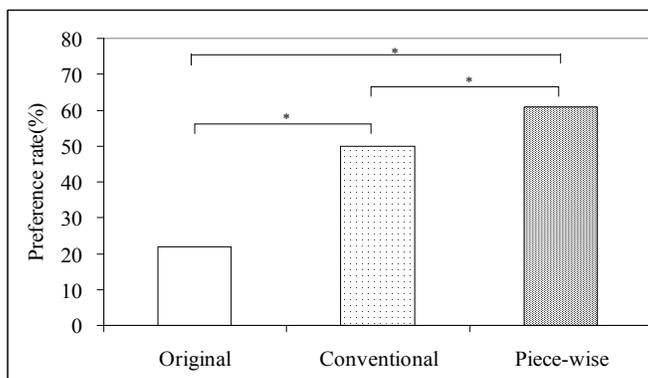
Figure 8. Patient's preference rate of stretching function evaluation. She strongly preferred the piece-wise stretching function over the conventional stretching function. She preferred images enhanced by either method over the original images.

4. DISCUSSION

One of the advantages of electronic magnification devices is that they can provide variable and flexible magnification by electronic zooming. High level electronic zooming usually requires exposure adjustment on the sub-images. Because the camera exposure control is usually based on the whole image, that may result in some sub-images having low contrast, which can be improved using image enhancement. For low contrast sub-images, conventional histogram stretching often causes over- or under-enhancement, and even flickering video images. Our evaluation with normally sighted subjects and a CFL patient showed that our piece-wise stretching enhancement based on a Gaussian weighted histogram was preferred over the conventional linear histogram stretching method. Therefore, it is suitable to be implemented in digital magnification devices.

The Gaussian weighted histogram focuses on the center of interest, and places less weight on the edge of the sub-images. This method of histogram counting places more weight on the region of interest than the conventional histogram counting method. It has two advantages. First, the gain is greater than that of the equally weighted histogram when dark or bright incidental features exist near the edge of the sub image, allowing greater enhancement of the region of interest. When the local histogram distribution is uniform across an image, the histogram estimated by Gaussian weighted function is similar to that estimated by equally weighted histogram counting method. This results in a similar enhancement effect for the two methods. Second, dark or bright objects entering or departing the sub-image may cause dramatic changes in the histogram distribution if the histogram is counted with equal weight. This causes drastic changes in enhancement gain and can result in flicker. Such dark or bright objects have less impact on the Gaussian weighted histogram counting method. The image intensity with the proposed method does not fluctuate as much. Highly enhanced details and mitigated flickering were the major reasons that the subjects preferred the center emphasized histogram.

As for enhancement gain, subjects preferred the piece-wise histogram stretching over the conventional linear histogram stretching function. For low contrast images, the gain of the conventional histogram stretching is usually too high, and therefore often results in over-enhancement and even binary artifacts. The gain of the piece-wise histogram stretching function is designed to deal with very low contrast images, effectively minimizing the probability of over-enhancement. Our study, however, showed no significant preference for enhanced images (conventional or piece-wise stretching functions) over the original image. This might be because in this study all the sub-images comprising the full images were used for the evaluation of stretching function, and the proportion of sub-images that needed enhancement was not very large. For 20% of the sub-images, subjects had no preference for one over the other, and for 32% of the sub-images, they preferred original version only. In other words, the overall exposure of the full images was appropriate for many of the sub-images. Evaluation using only low contrast sub-images would more clearly show the differences. Anyhow, piece-wise stretching was preferred more significantly than the conventional function. Our finding of no difference in preference between original and enhanced images may be also related to individual preferences. Two of the six subjects had a low tolerance to enhancement artifacts. Bronstad et al. reported similar individual differences in preference for image enhancement[11]. The measurement of image quality may be complicated by individual preference differences and possibly by video content. Therefore, different options should be available to meet individual preferences.

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